A NOTE ON CLEAR AIR TURBULENCE DURING APRIL AND MAY 1960

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1. INTRODUCTION

During the months of April and May 1960 a number of teletypewriter transmissions of pilot reports of clear air turbulence in the United States were gathered for a study of this phenomenon. The study was undertaken to see if any clues to forecasting clear air turbulence in the levels between 500 and 300 mb. could be found. These levels were chosen because of the larger number of flights that are made at levels between 18,000 and 30,000 ft. both by jet and turbo-prop aircraft. The approach of this study was to outline areas where clear air turbulence was encountered by pilots and to examine these locations in relation to upper-air flow patterns, horizontal and vertical wind shears, and 500-mb. height changes.

2. CLEAR AIR TURBULENCE IN RELATION TO UPPER-AIR FEATURES

Clear air turbulence was most often reported when the 500-mb. flow showed a closed Low or a well defined trough as its primary circulation. In this type of circulation, the turbulence was quite often reported to the east and southeast of the trough line or low center and immediately to the west of the area of maximum winds and was associated with strong horizontal shear. Figure 1 shows a typical 500-mb. pattern when clear air turbulence was reported. In this case clear air turbulence was reported at levels between 17,000 and 21,000 ft.; all reports indicated moderate to severe turbulence. Strong horizontal and vertical shear was present, as is shown in figure 2, a cross section from Peoria, Ill. to New York City based upon upper-air observations 2 or 3 hours before the time of the turbulence reports.

Figure 3 shows a case of closed circulation at 300 mb. that was associated with reports of clear air turbulence. Turbulence was reported at 29,000 ft. in the vicinity of Morgantown, W. Va. about 2 hours before the time of the upper air observations. Earlier in the day, severe clear air turbulence was reported at 31,000 ft. between Cleveland and Chicago. Figure 4 shows another type of upper-air pattern that gave rise to clear air turbulence.

Balzer and Harrison [1] noted a lack of cases of clear air turbulence over the Rockies and northern Plains. A possible explanation of this could be the mean positions of troughs and ridges aloft over the United States: a mean ridge lies over the Rockies, and a mean trough farther east over the Central States [2]. This would give a greater amount of clear air turbulence over the area from the eastern Plains eastward to the east coast. Along the Pacific coast, it is not uncommon in certain portions of the year to have a cut-off Low over the southwestern United States, and along the California coastline, with a trough northward along the coast. In these cases, a greater amount of clear air turbulence cases would occur in the western United States. Clem [3] showed a clearcut maximum level of clear air turbulence over the southwestern and northwestern United States between 27,000 and 40,000 ft. in winter, and this would fit the pressure patterns for clear air turbulence.

In the study of horizontal wind shear in relation to

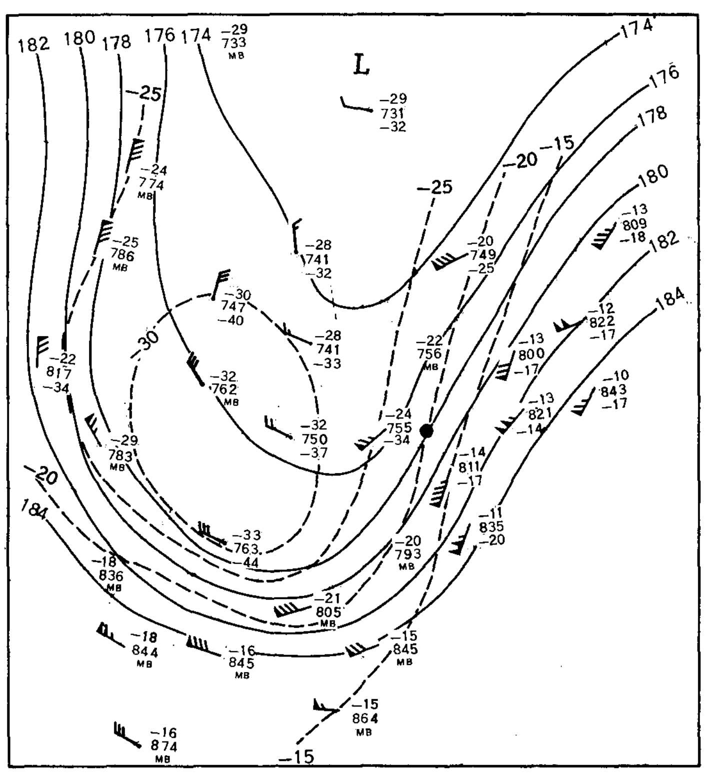

FIGURE 1.—500-mb. chart, 1200 GMT, April 5, 1960. Solid lines are contours; dashed lines are isotherms; solid circle indicates report of clear air turbulence.

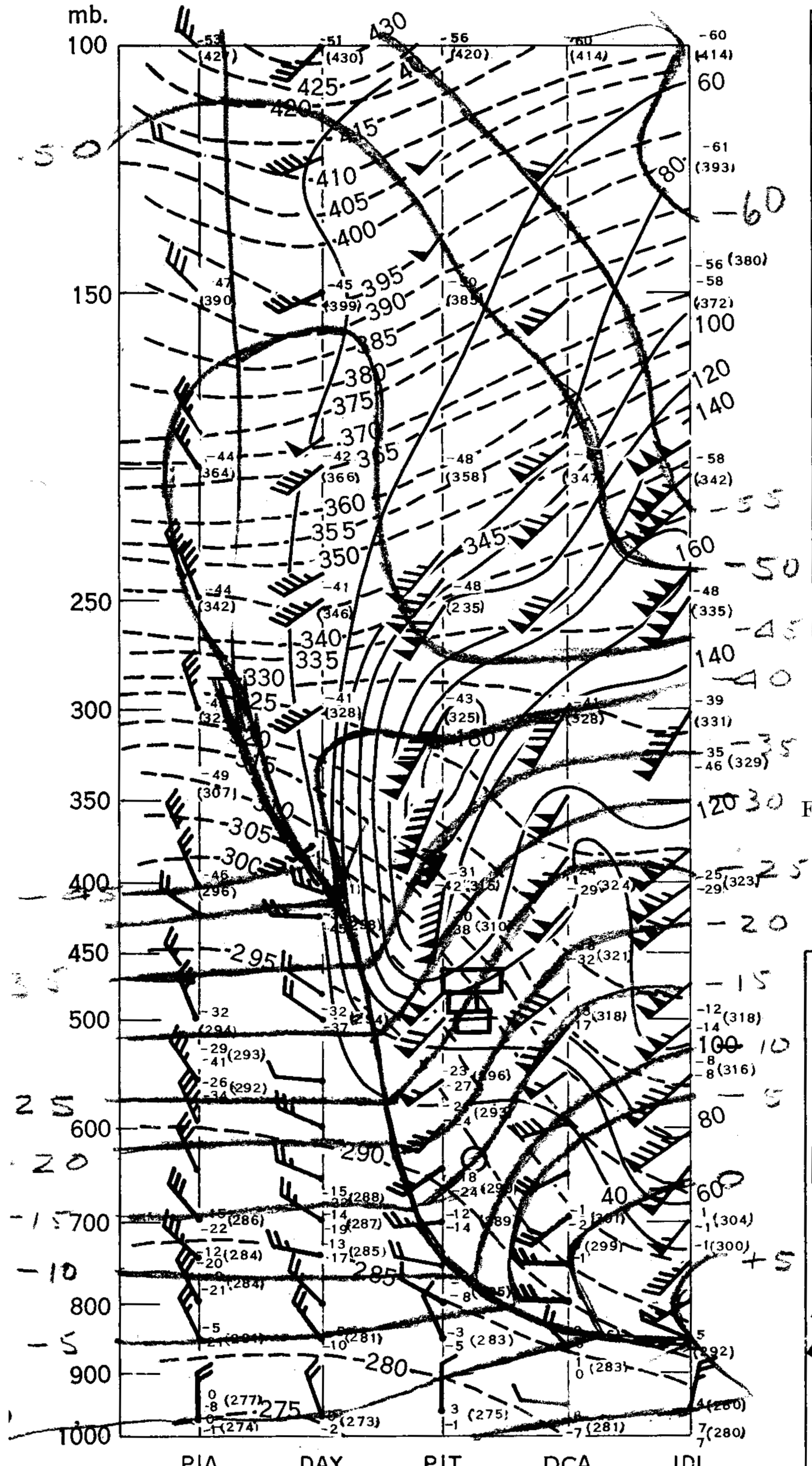

FIGURE 2.—Vertical section from Peoria, Ill. to New York City, 1200 GMT, April 5, 1960. Solid lines are isotachs; dashed lines are isentropes; blocks indicate reports of turbulence; circle indicates report of smooth air.

clear air turbulence, it would seem that the direction of travel of the aircraft would be a factor in the effect of the turbulence on the aircraft. In those reports of turbulence for which the direction of aircraft travel could be determined it was found that the direction was most

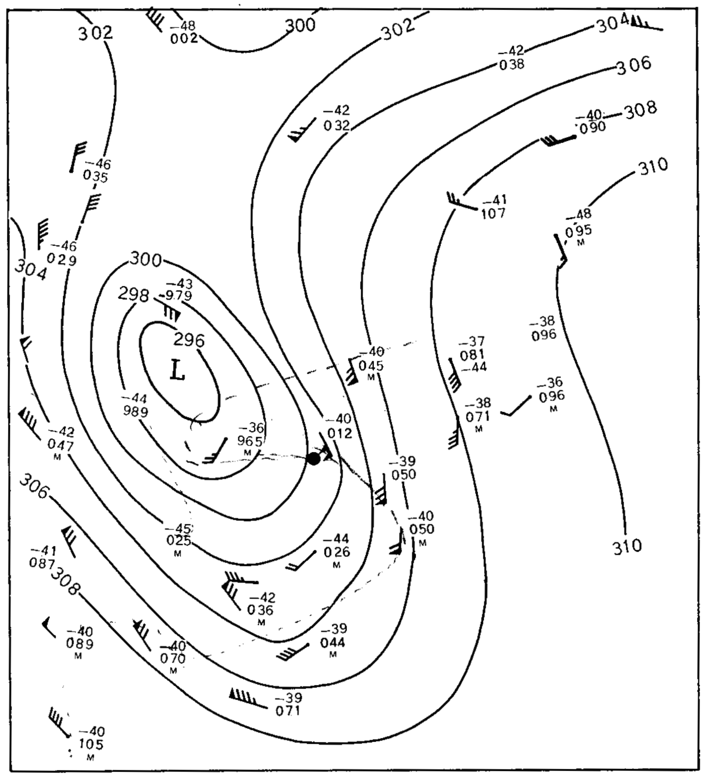

FIGURE 3.—300-mb. chart, 0000 GMT, May 9, 1960. Solid lines are contours; solid circle indicates report of clear air turbulence.

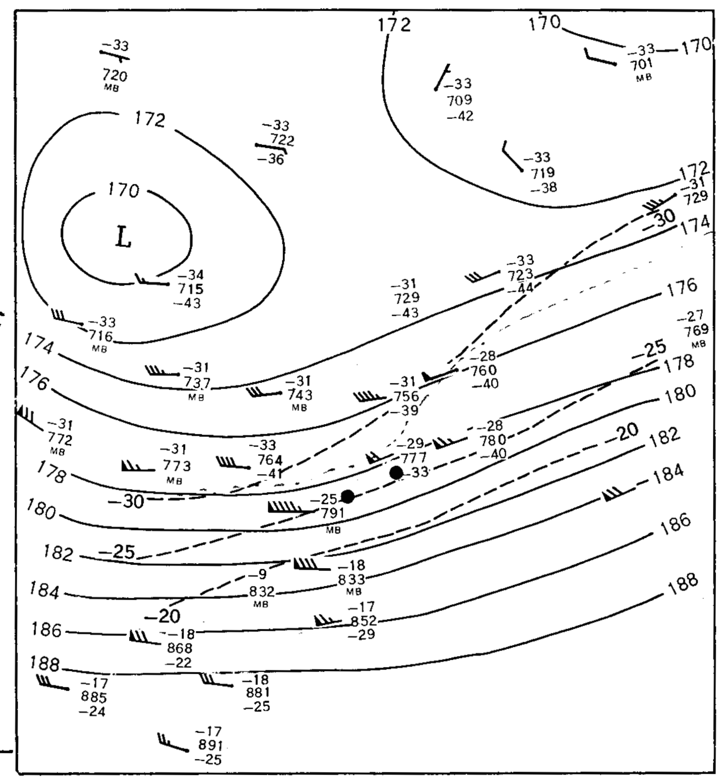

FIGURE 4.—500-mb. chart, 1200 GMT, April 8, 1960. Solid lines are contours; dashed lines are isotherms; solid circle indicates report of turbulence.

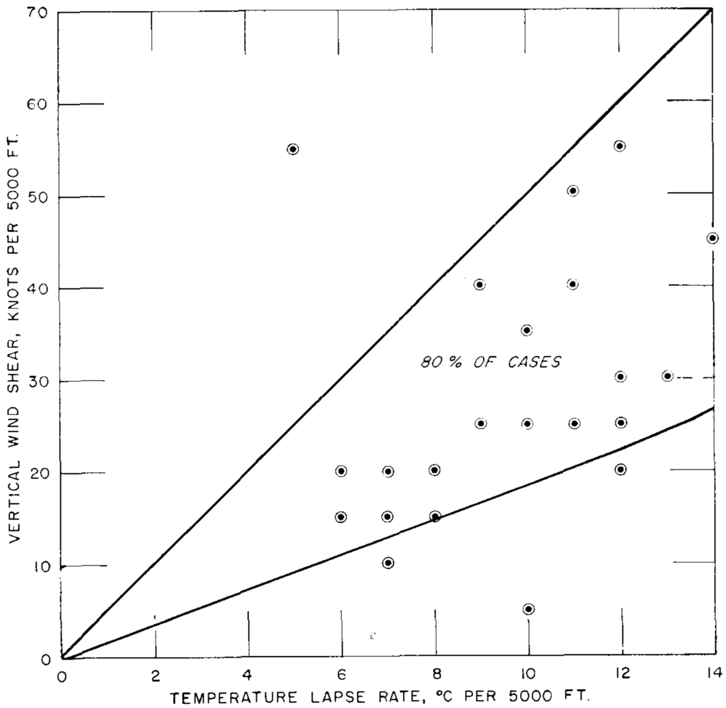

Figure 5.—Clear air turbulence reports during April and May 1960, plotted as a function of vertical wind shear and temperature lapse rate.

often from the low pressure to the high pressure side of the upper-level flow and most often was nearly perpendicular to the streamlines. An added effect in cases where a well-developed trough existed, especially at 500 mb., was upslope motion, as suggested in figures 1 and 4 by the isotherms.

Arakawa [4] derived an equation that yields a critical value of horizontal shear of 15 knots per degree of latitude. Any value above this limit would yield heavy turbulence. Harrison and staff [5] give a critical shear value of 50 knots per 150 nautical miles. It is thought, however, that because clear air turbulence is generally reported in a narrower horizontal band than 150 miles, the practical calculation of shear from the wind difference over a finite normal distance should perhaps use an interval of about 50 nautical miles. This would yield more representative values of the shear necessary to produce clear air turbulence. It is unfortunate that the wide spacing of upper-air reporting stations makes use of this smaller interval extremely difficult.

In an attempt to correlate vertical wind shear and vertical temperature gradient over a 5,000-ft. interval in the turbulence cases, a great variation in the paired values was found. Figure 5 shows pilot reports of clear air turbulence plotted with ordinate of vertical wind shear over a 5,000-ft. interval regardless of sign and abscissa of change in temperature in degrees Celsius over the same vertical interval. The cases studied make up only a small sample, but they do indicate that clear air turbulence can exist with a vertical wind shear of less than 10 knots per 5,000 ft., and with temperature lapse rates of 5° C. per 5,000 ft. or greater. The graph shows that a vertical wind shear of 15 knots per 5,000 ft. is enough to produce clear air turbulence if the lapse rate is more than 5° C. per 5,000 ft. The strong vertical wind shear of 55 knots per 5,000 ft. that is plotted on the graph (fig. 5) is for the same date and time as figures 1 and 2.

Clear air turbulence was reported in areas of 24-hour height falls at 500 mb. The correlation here was only a little over 0.5, but suggests a relation of kinetic height changes to clear air turbulence. Taking the changes over a 24-hour period tends to mask such a relation; it is believed that if changes over a smaller interval of time, say 6 hours, could be computed, a better relation between clear air turbulence and height changes at 500 mb. might be found.

3. SUMMARY

Clear air turbulence was most often reported at levels above 15,000 ft. whenever the 500-mb. chart showed a closed Low or a well defined trough. The turbulence was then found in the southwesterly flow ahead of the trough line, on the low pressure side of the maximum wind field.

The reports received indicated the existence of clear air turbulence in the vicinity of the jet core, on the poleward or cold or low pressure side of the jet; this is in close agreement with the findings of Bannon [6] and Jones [7] in investigations of clear air turbulence in the British Isles. But clear air turbulence is not a phenomenon of the jet stream alone, for it was reported as far as 20,000 ft. below the level of maximum winds.

There was evidence that a strong horizontal shear across a trough line adds to the intensity of clear air turbulence. Some evidence pointed to the existence of clear air turbulence in the right quadrant of negative height falls at 500 mb., but the correlation was not very strong.

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